NG UAS-Based SPECTRAL SYSTEMS FOR ENVIRONMENTAL MONITORING

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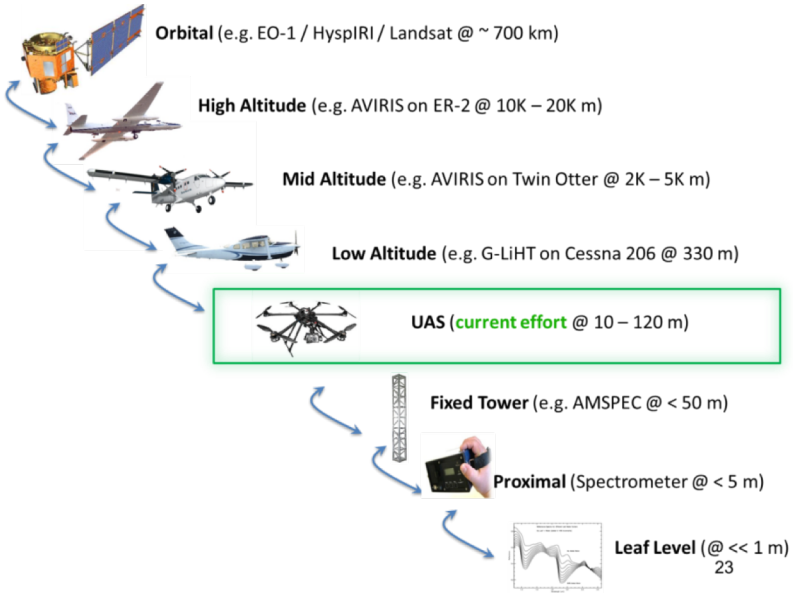

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Application Goals

UAV based science quality spectral systems, measuring both reflectance and fluorescence are needed for efficient remote sensing monitoring, including:

- Ecosystem Management - Forestry and Bio-diversity Management, Precision Farming
  - repeated monitoring at the right time
  - monitoring at the right scale and rate of specific trait variation
  - scaling from field to stand and regional scale

- Carbon cycle and ecosystems function
  - reflectance captures the bio-physical traits with seasonal dynamics, such as canopy nitrogen, photosynthetic pigments, LAI, non-photosynthetic material
  - solar induced fluorescence (SIF) provides a direct probe to vegetation photosynthetic function, capturing it's diurnal and seasonal dynamics

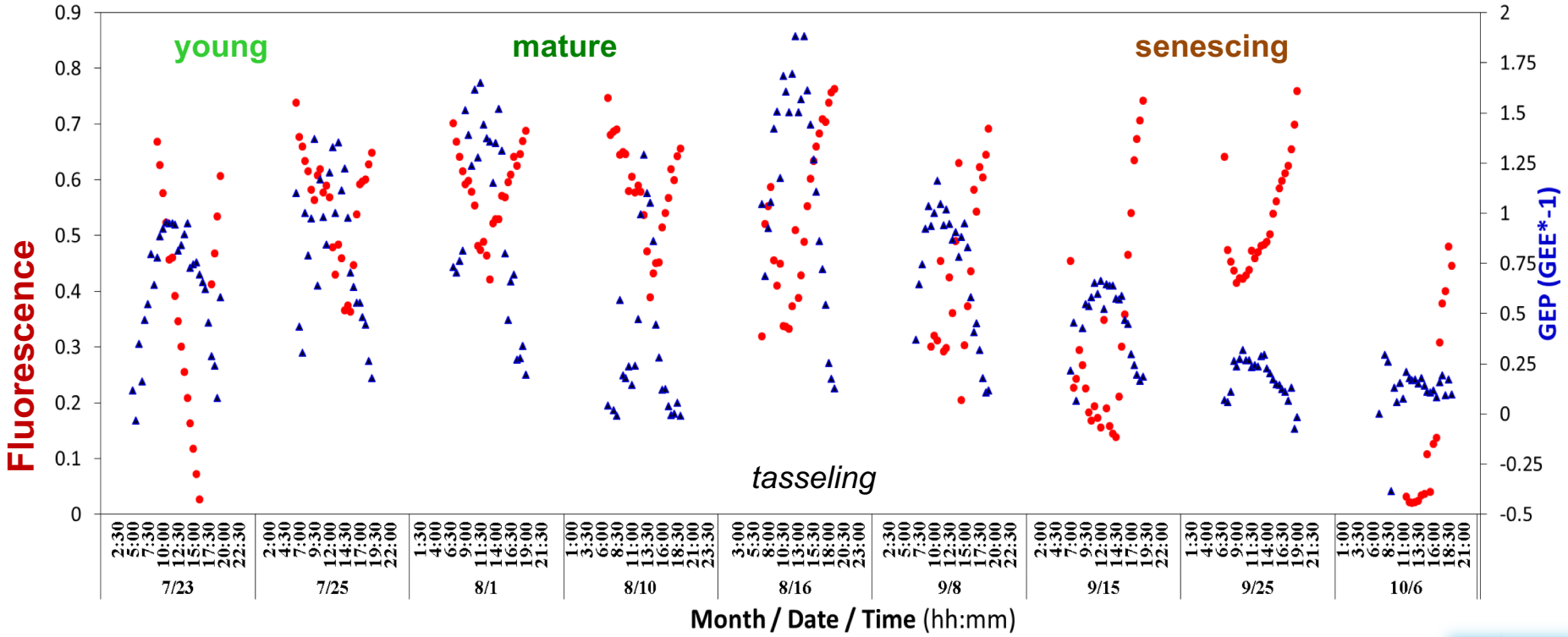
- Extreme climatic natural and anthropogenic events
  - disaster response
  - aircraft and satellite measurements may not exist , or be feasible

Next Generation Monitoring – automated, calibrated and flexible (e.g. scale and frequency) reflectance and fluorescence data acquisition.

Photograph by Don Deering

Vegetation Diurnal and Seasonal Trends

Why High Spectral Resolution UAS?



Fluorescence **RED**, MONI-PAM (µmol m^{-2} s^{-1})

GEP **BLUE**, FLUX tower (mg m^{-2} s^{-1})

Corn under optimal nitrogen deposition (N=100%, OPE3/USDA, MD)

Canopy traits - chlorophyll, chemistry, productivity and SIF

Science Objectives & Approach

Goal: develop a high spectral resolution Unmanned Aerial System (UAS), with line and imaging spectrometers capable of producing science-quality spectral data for retrieval of biochemical and physiological traits

Objective: identify key instrument and flight challenges that can be resolved to **maintain the quality of the spectra**

- Optimization – consistent SNR = optimal integration time
- Canopy diversity - sun, shade, closure

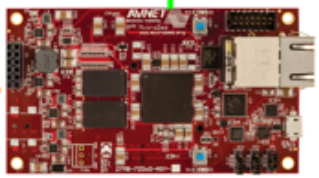
Approach: employing an intelligent gathering scheme to semi-automate

- spectral data acquisition,
- processing workflows, and
- tasking and operation strategy

System Components and Architecture

Power Source

Processor to Navigate Bergan UAS



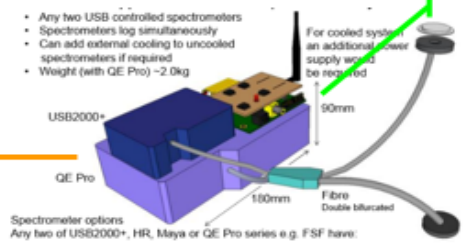
USB/RS232

Intelligent Payload Module (IPM) for: on-board processing, adjustments and communications; includes Two Arm Processors and Field Programmable Gate Array (FPGA)

Ethernet

Nano-Hypserspec with Internal FPGA based Processor to Capture Data

Raspberry Pi 2 – internal to the Piccolo

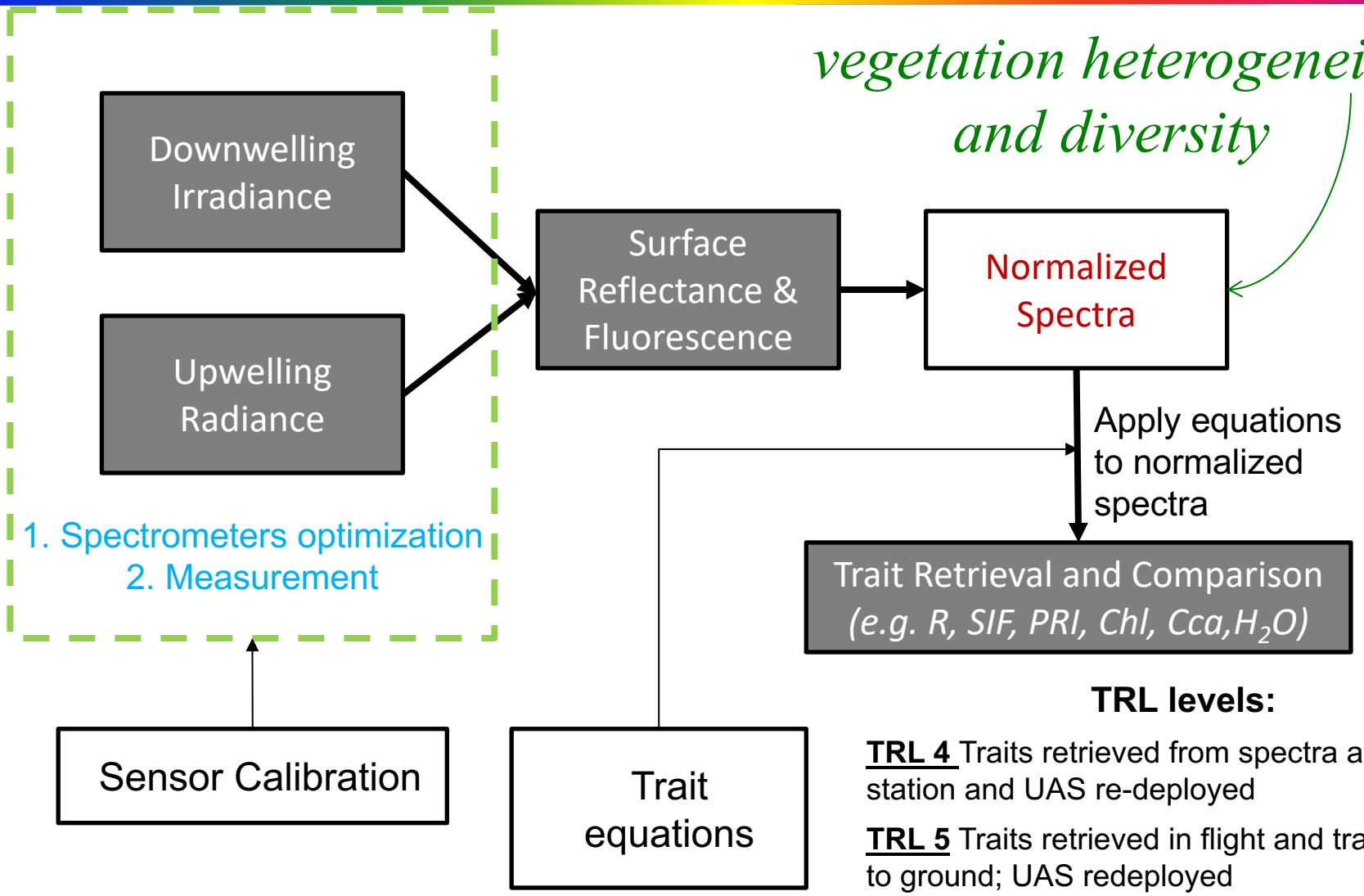


Piccolo with QE Pro, and Flame spectrometers

Power

Data

Generalized Data Processing Workflow for Retrieval of Canopy Traits



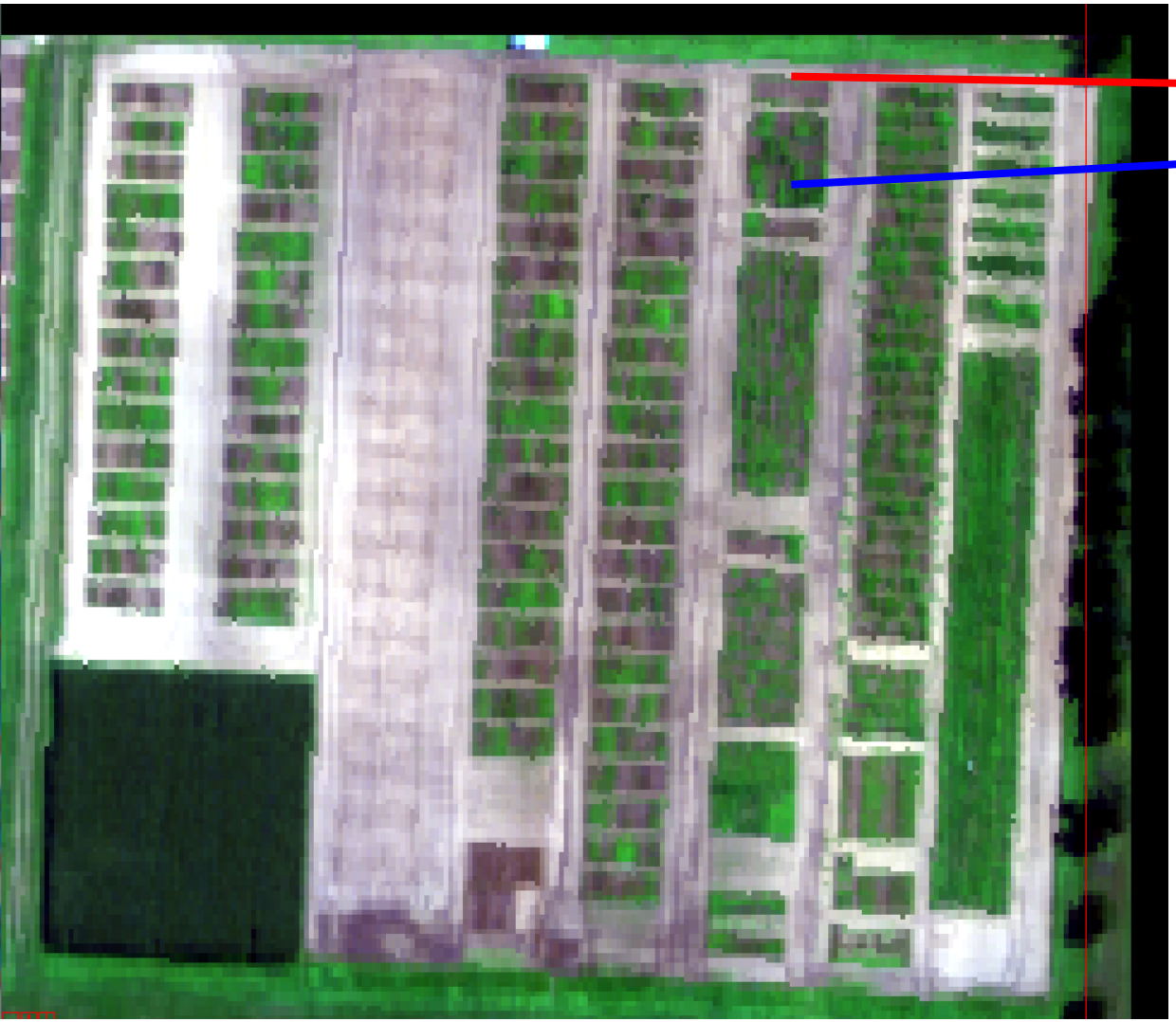
TRL levels:

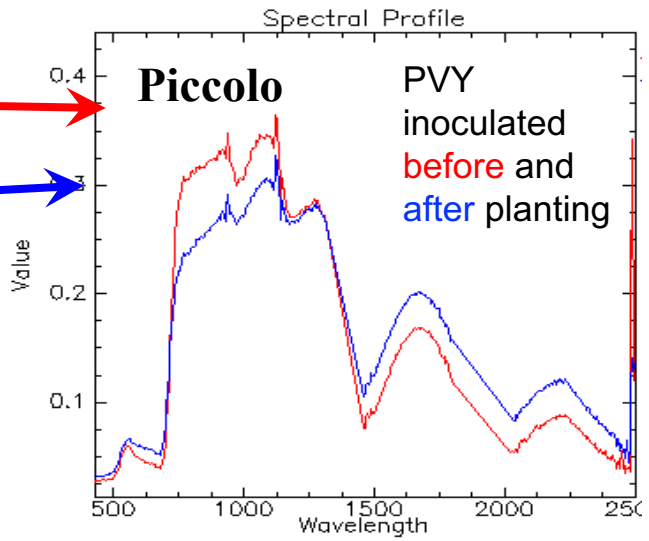
TRL 4 Traits retrieved from spectra at ground station and UAS re-deployed

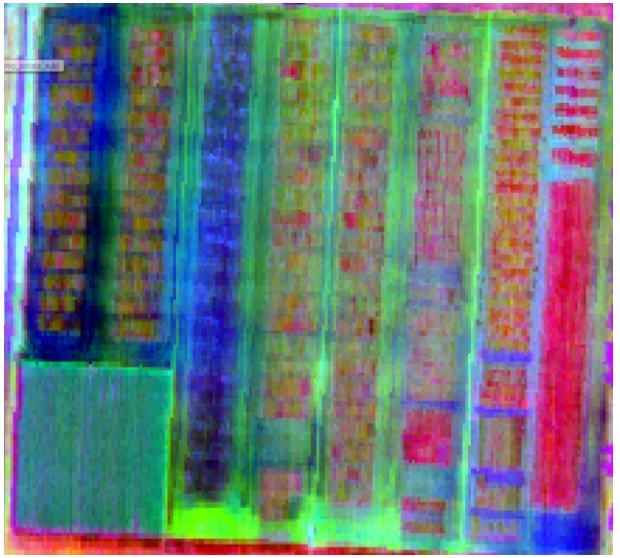
TRL 5 Traits retrieved in flight and transmitted to ground; UAS redeployed

TRL 6 Traits retrieved in flight and transmitted to ground, UAS moves to new location

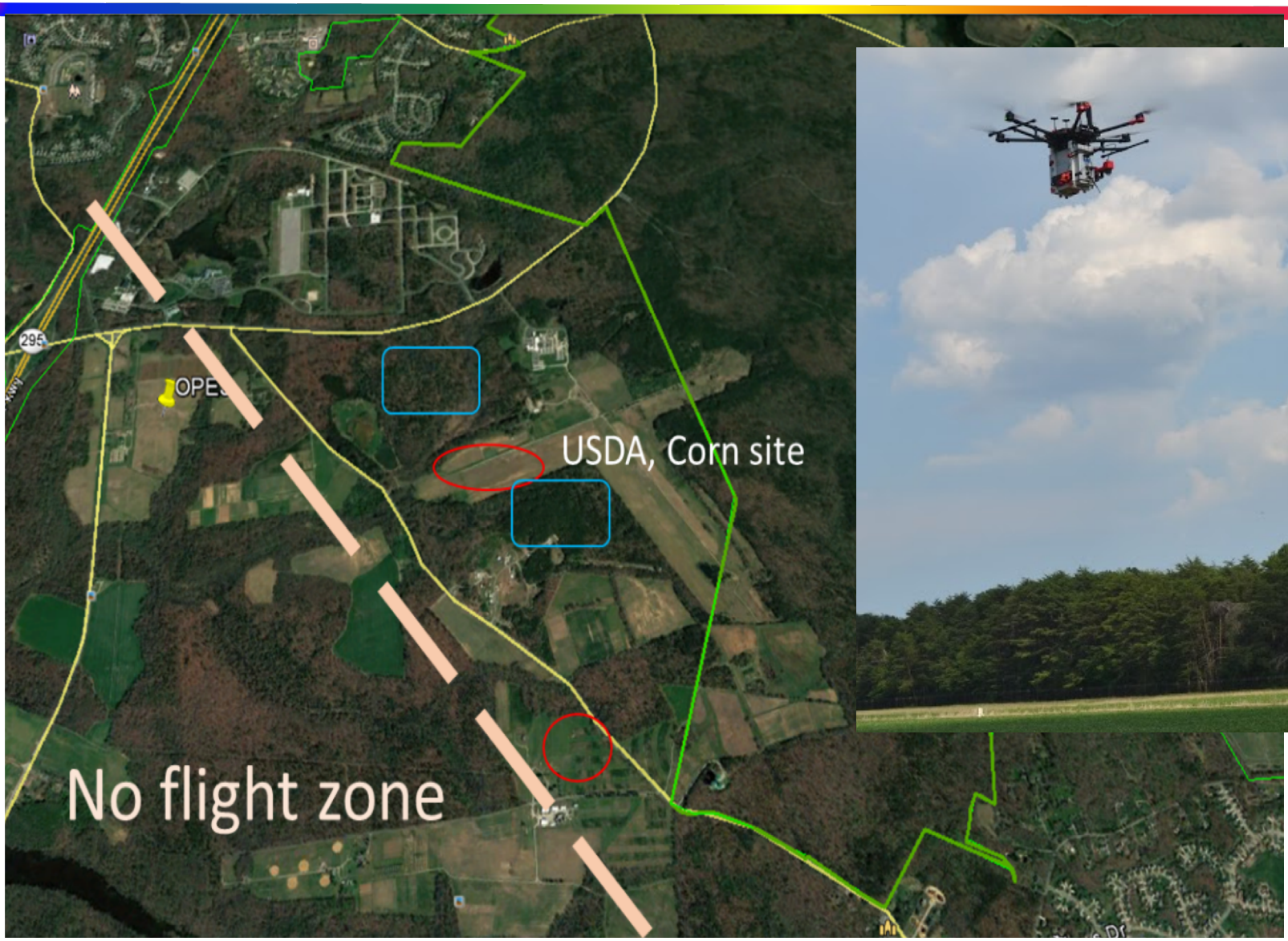
Potato Virus Y (PVY) Vegetation Stress Trials, Madison, WI



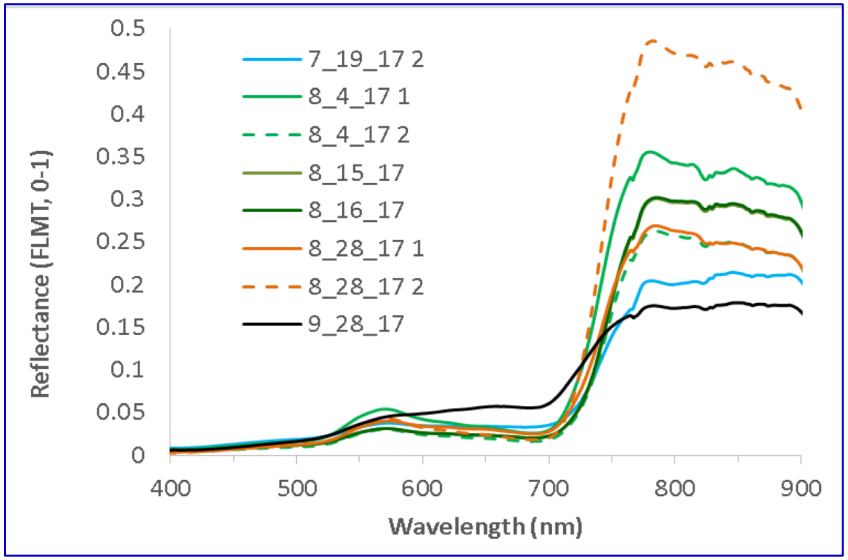




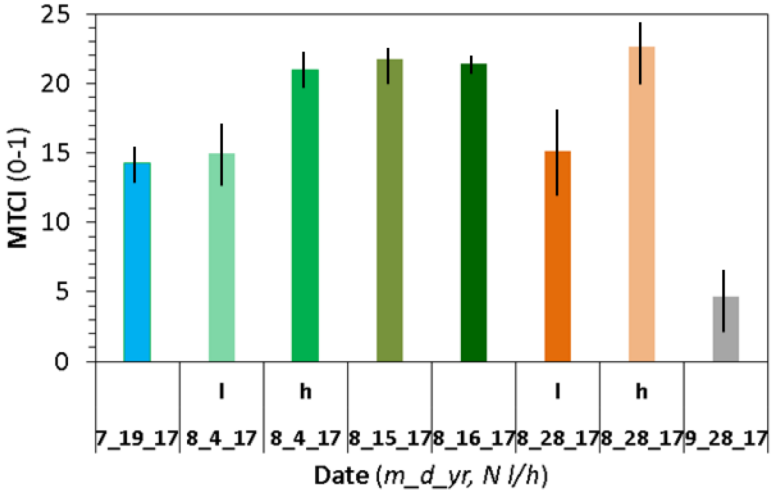
Measurements in Greenbelt, MD 2017



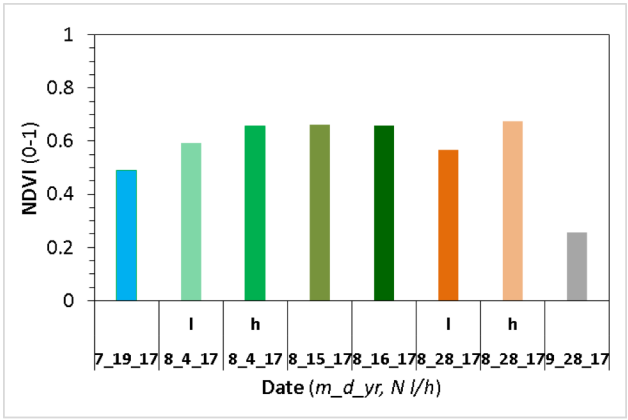
Seasonal Trends in Canopy Chlorophyll
(Piccolo: FLMT, OPE3, Corn, MD)



Canopy Chlorophyll (MTCI)



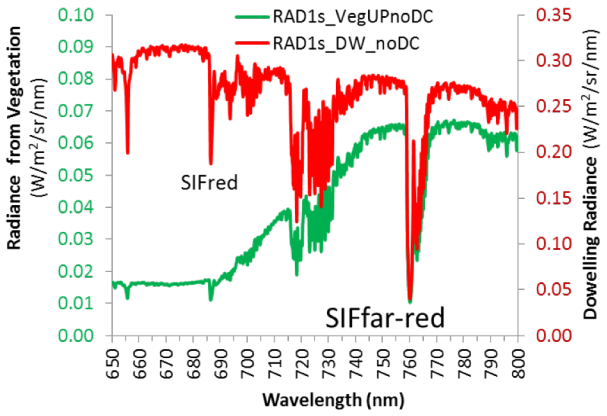
Canopy Greenness (NDVI)

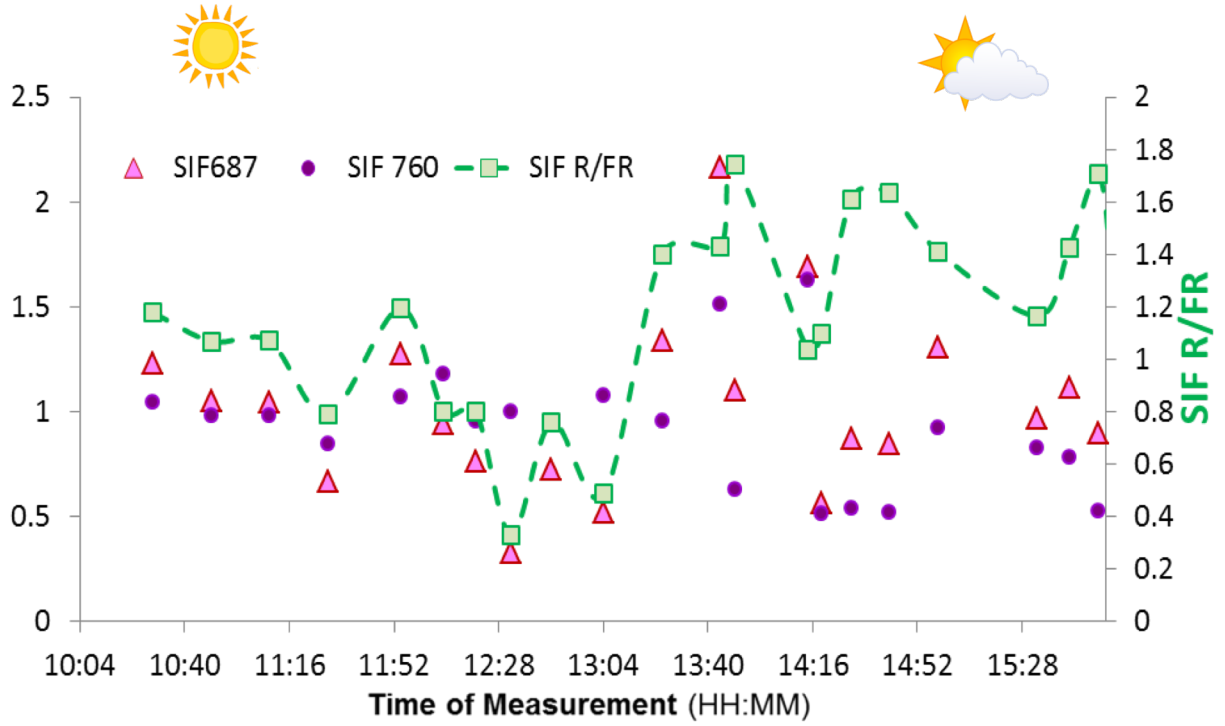


NDVI	R(760- 721)/R(721+760)
MTCI	(R 750 – R 710)/(R 710 – R 680)

Solar Induced Fluorescence of Corn, USDA/ARC, MD

Diurnal, (Piccolo, QEPro)





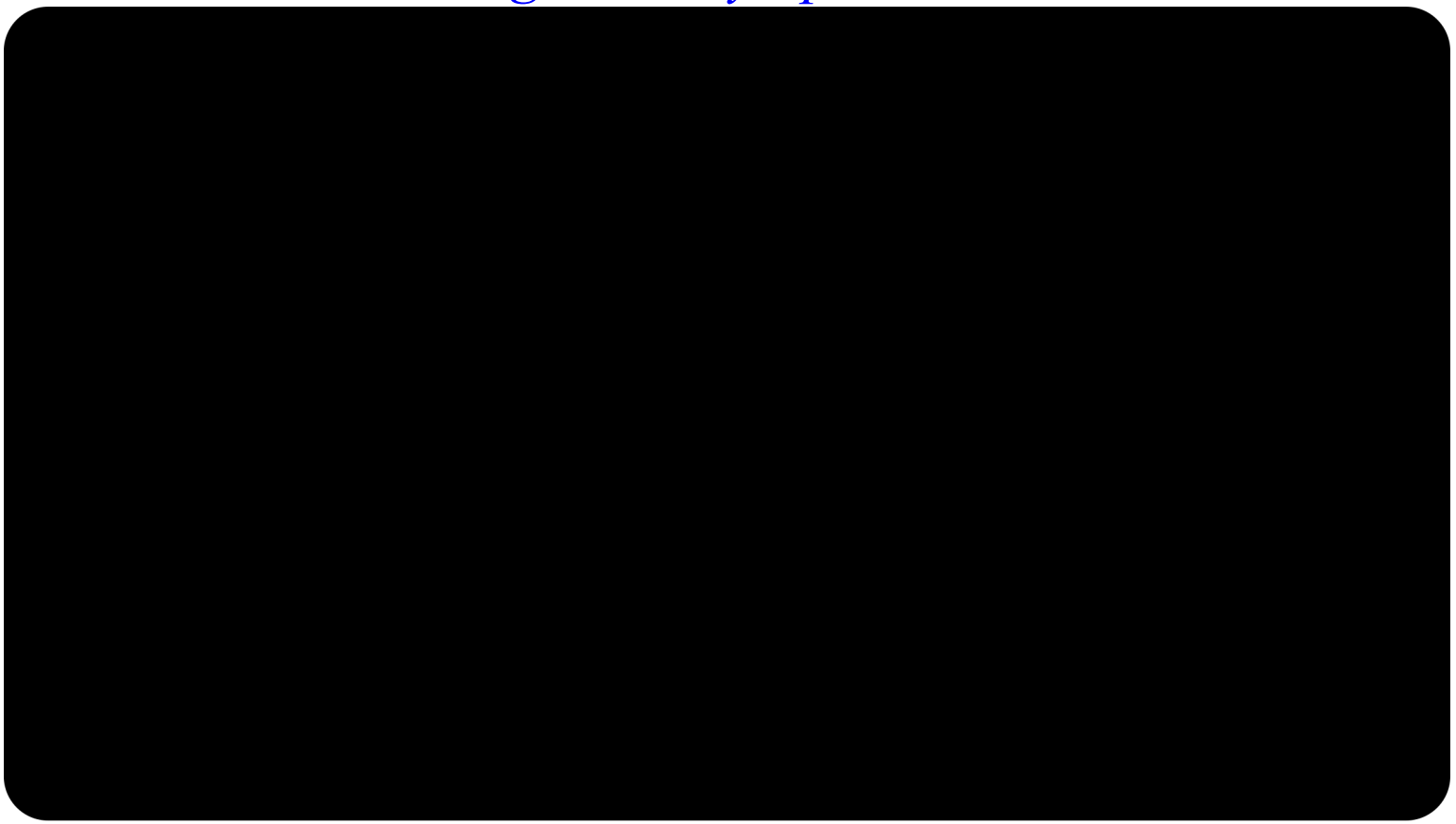
Status: Spectrometer optimization is automated, testing was successful for characterization of biophysical traits in ~uniform canopies across the season.

Objective in 2018: *enhance the current spectral UAS system by adding capability for characterizing the differences in canopy structure*

- Address key challenges comparing canopies with very different canopy structure
- Approach / workflow
  - *VNIR image collection at 0-10 degrees off nadir*
  - *generate a stereo pairs or dense point cloud cover*
  - *for each collection determine: shadow fraction, canopy density and photosynthetic component*
  - *normalize spectra/image for canopy differences*

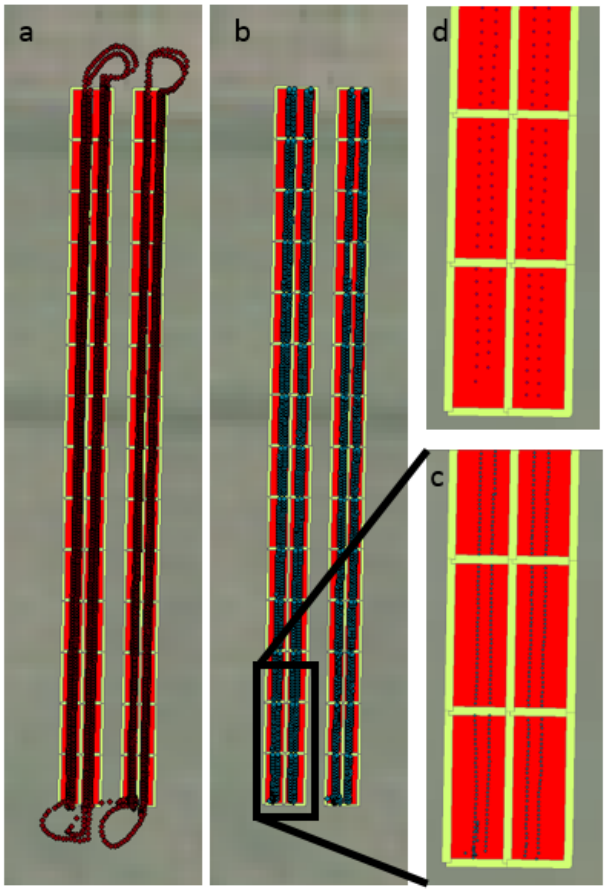
2018

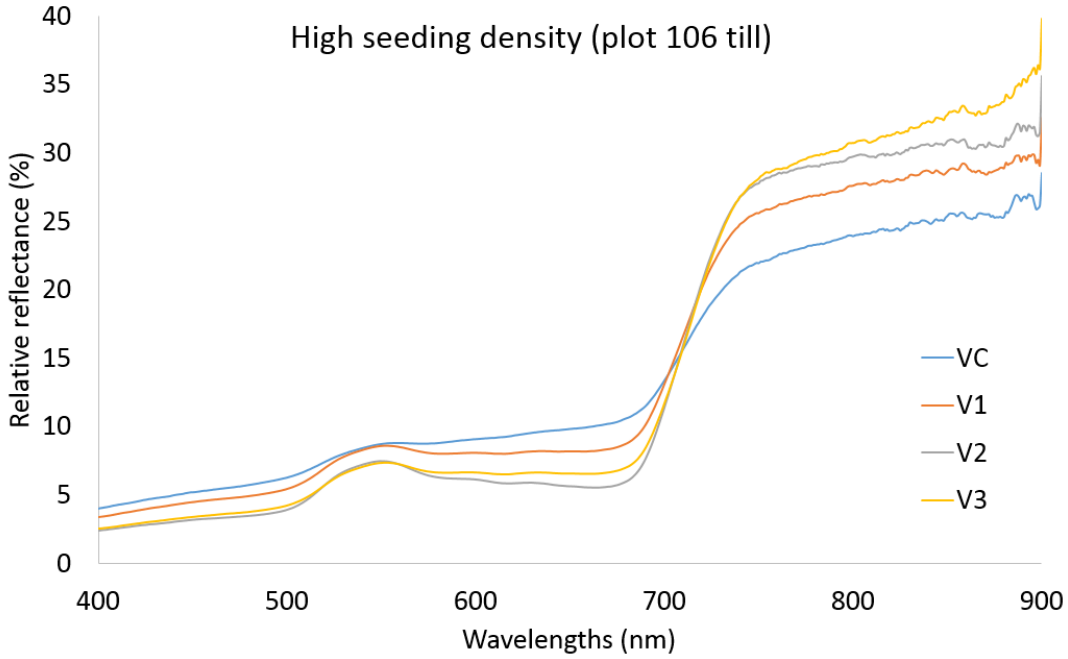
Problem 1: Optimizing the spectrometers for different light conditions, *issues: rapid changes in light, leading to slow optimization = no enough battery / power and time…*



Background: 15 minute flights due to battery life and 5 – 40 seconds needed to acquire measurement; multiple integration times have to be adjusted depending on cloud cover for each spectrometer optics, for each measurement

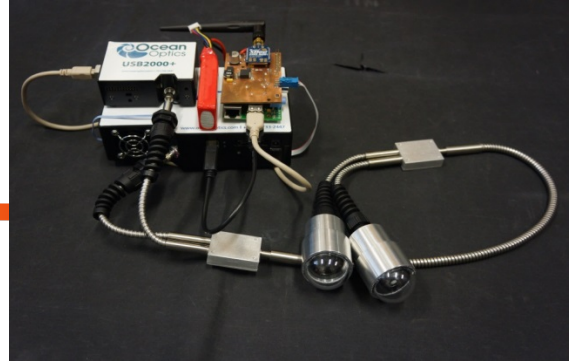
Piccolo: Soybean Seeding Density in Till and No-Till Fields, Madison, WI

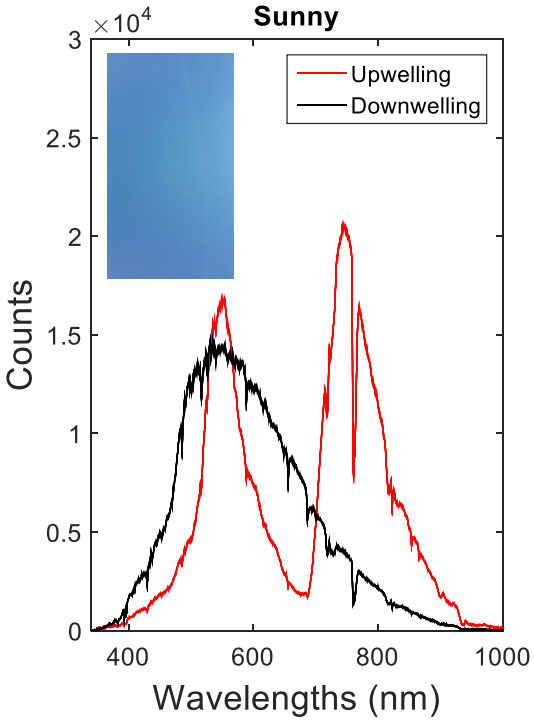


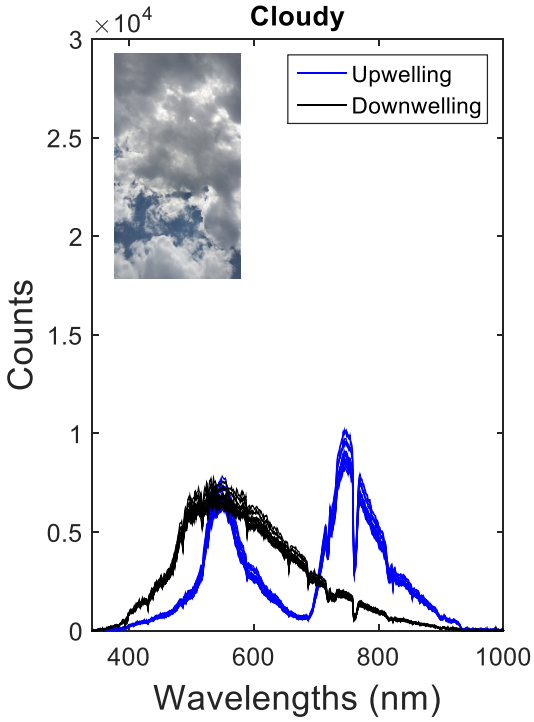


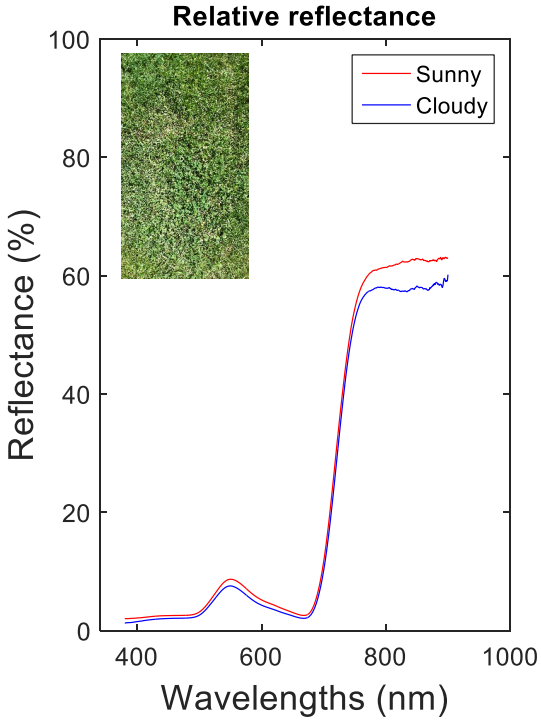
The spectral evolution of a high seeding density till plot in the emergence experiment. Spectral data obtained in four development stages from vegetative cotyledon (VC) to vegetative 3rd trifoliate (V3).

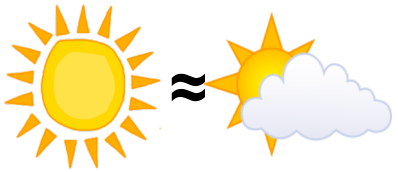
Why Piccolo



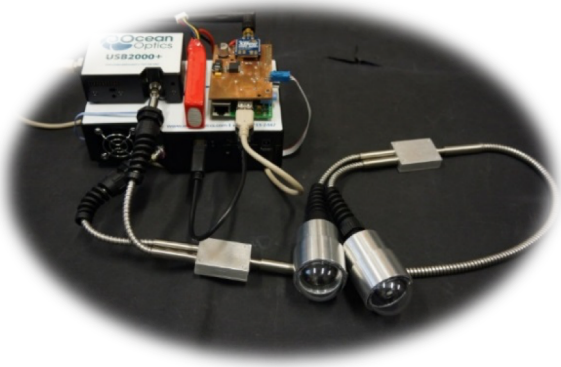

Sunny
×10^4
Upwelling
Downwelling
Counts
Wavelengths (nm)


Cloudy
×10^4
Upwelling
Downwelling
Counts
Wavelengths (nm)

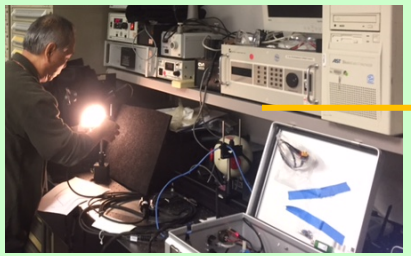

Relative reflectance
Sunny
Cloudy
Reflectance (%)
Wavelengths (nm)

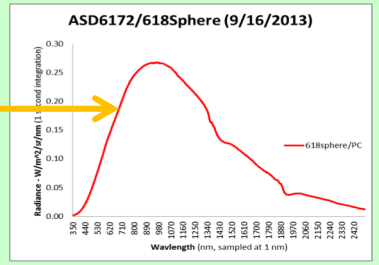


Calibrated Piccolo Output - Digital Numbers to Radiance

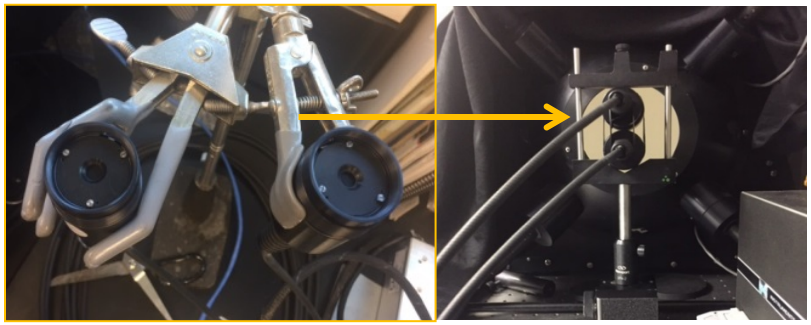


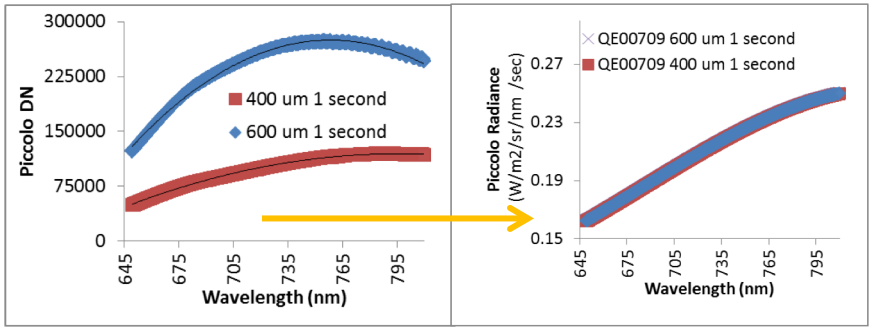
Calibrated sphere providing radiance



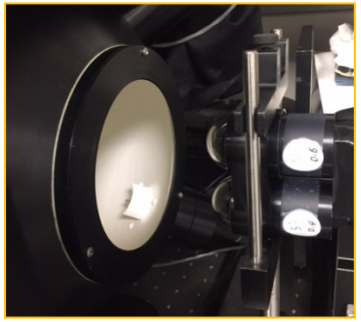


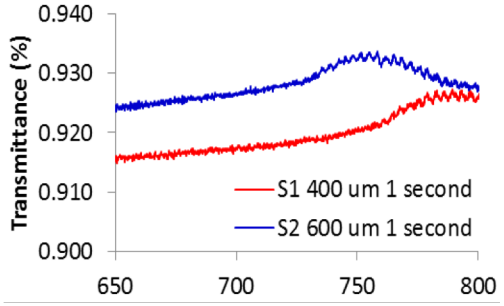
1. Calibration of the piccolo fore optics, without the glass domes and without the diffuser



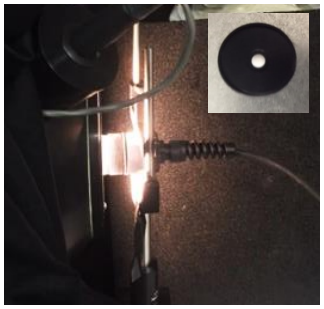


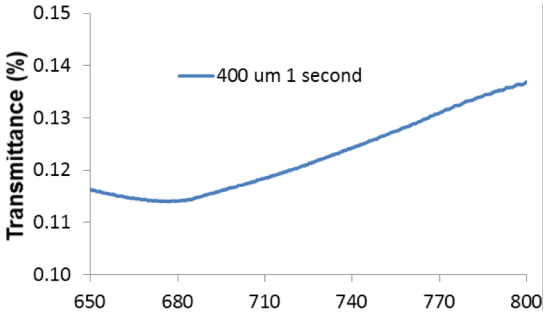
2. Glass domes transmittance (no diffuser)





3. Transmittance of the QEPro 400 um fiber diffuser

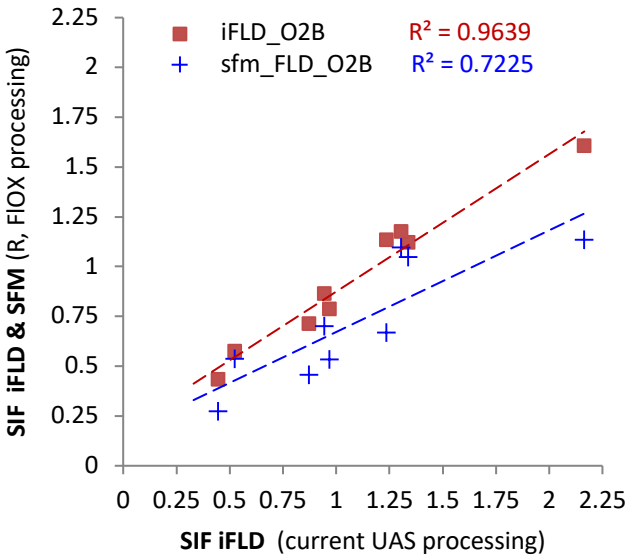


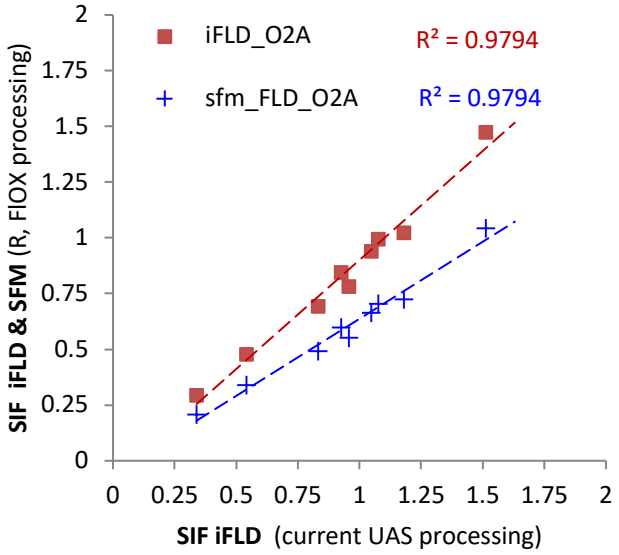


Piccolo: Solar Induced Fluorescence

Considerations:

- SIF retrievals approaches





2017 Field Measurements: June-September

1) Arlington and Hancock Agricultural Research Stations (Madison, WI)

- Biofuels Diversity Experiment (testing approaches to maximizing productivity and ecosystem services).
- Aspen Competition Garden (differing density), Aspen Genotypes Garden (hundreds of genotypes).
- Cranberry plots (N) and Soybean Trials (varying varieties).
- FREQUENCY: Weekly for all and diurnal for crops.

2) Cedar Creek LTER (East Bethel, MN, 30 mi north of St. Paul)

- BigBio diversity project, 1 - 16 species (324 manipulated plots);
- below and above ground processes, including traits

3) USDA/Greenbelt and UMD Farm

Just outside the DC no-fly zone (red at left) making it one of the few areas near GSFC where we can work. Corn, multiple row crops.

To be used for diurnal and seasonal observations and engineering tests.

FREQUENCY: Eight sortie days beginning June 2017.

- ➢ New technology experiments will be sequentially folded in as the as the growing season progresses

Acquisitions on 7-17-17

Why Spectrometry and Why from UAS

Measurements: WHAT, WHERE and WHEN?

Science objectives: consistent characterization of diurnal and seasonal cycles in canopy vegetation function; extrapolating from point measurements to 30 m and up…

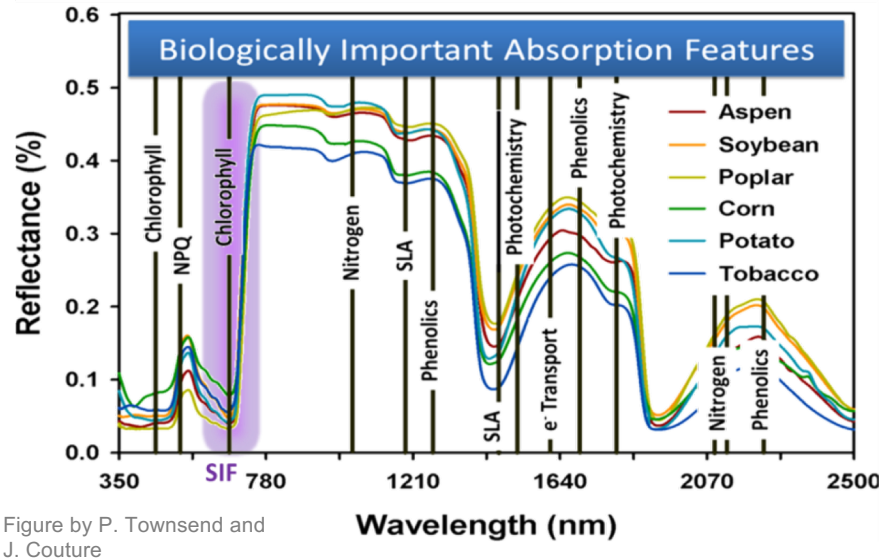
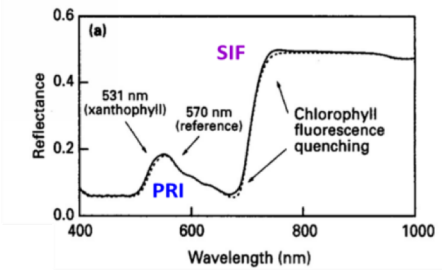
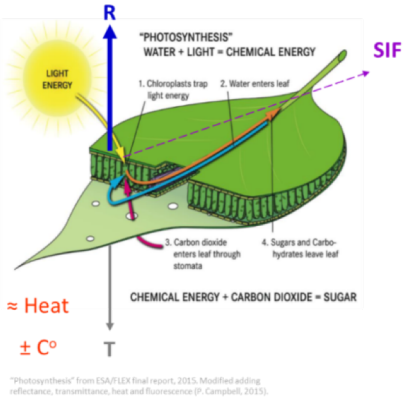


Figure by P. Townsend and J. Couture



- ✓ Vegetation water content, rate of photosynthesis and the associated reflectance spectra
- ✓ Solar Induced Fluorescence (SIF)



Some of the targeted canopy traits

- Chlorophyll, N
- Water
- Cellulose